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ARE BOSE-EINSTEIN CONDENSATES SUPERFLUID? Previously physicists have demonstrated that Bose Einstein condensates (BEC is created when trapped atoms are chilled so low that they begin to overlap) constitute a single macroscopic quantum state, which implies superfluidity. However, physicists would like to see frictionless flow more directly. Two new experiments pave the way toward this goal. A NIST/Colorado group has observed quantized vortices in a condensate of rubidium atoms, while an MIT group has observed that objects can move through a condensate of sodium atoms and lose little or no energy if the velocity is below a certain critical value. In the Colorado/NIST work (Carl Wieman, 303-492-6963, cwieman@jila.colorado.edu) the BEC state consists of atoms residing in two separate spin states (referred to as 1 and 2). Using microwaves and a separate probe laser beam working at the fringe of the condensate, the spins of 1-state atoms are flipped, turning them into 2-state atoms in one sector of the condensate after another. This sets a vortex of 2-state atoms into motion around the outer part of the condensate while 1-state atoms remain at rest at the core of the vortex (see the figures at www.aip.org/physnews/graphics). Thus the vortex is like a smoke-ring of 2-state atoms (with a filling of 1-state atoms) rotating about every 3 seconds. Furthermore, it has exactly one unit of angular momentum. Meanwhile the MIT group (Wolfgang Ketterle, ketterle@mit.edu, 617-253-4876) uses a focused laser beam to punch a hole in the BEC blob (the light repels atoms from its focus) and then scans the hole along at various speeds. The moving hole is equivalent to a moving object. Below a scan velocity of about 2 mm/sec, no energy dissipation was observed. The existence of such a critical velocity for frictionless motion is an attribute of superfluidity. One reason for this kind of BEC research, other than for studying fundamental aspects of a novel form of atomic matter, is that it might afford a new way of learning about superfluidity and superconductivity (both reports appear in the 27 Sep issue of *Physical Review Letters*: Colorado/NIST in M.R. Matthews et al. and the MIT work in C. Raman et al).

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EINSTEIN

Still right after all these years...

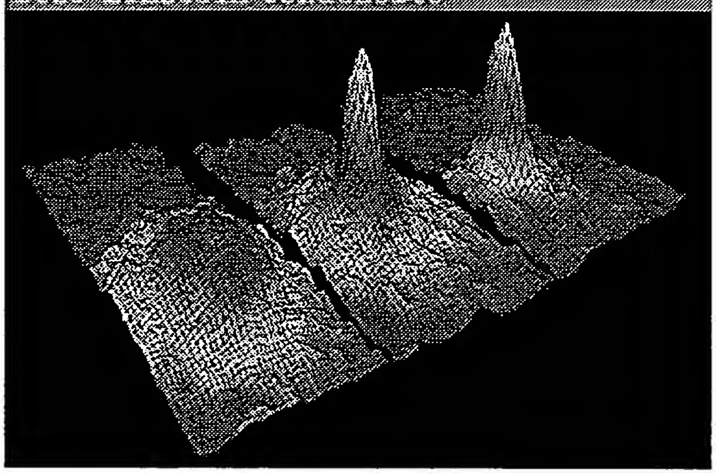
The ultimate chill-out proves Einstein right once again

Back when "automobile" meant model A, and "president" meant "Silent Cal" Coolidge, Albert Einstein predicted that a strange kind of matter would exist around absolute zero, a frosty -459.69 F, the coldest possible temperature.

Expanding upon the calculations of Indian physicist Satyendra Nath Bose, Einstein in 1925 calculated that at that temperature atoms would enter the same quantum-mechanical state.

In other words, they would be a drill sergeant's dream -- identical in mind and body.

Bose-Einstein condensate



False-color images show the velocity distribution of rubidium atoms a) just before the appearance of the Bose-Einstein condensate, b) just after its appearance and c) in a nearly pure condensate. The color shows the number of atoms at each velocity. Red = the least and white = the most. Atoms at the top are essentially stationary; the lower the atom, the faster its velocity.
Courtesy of Mike Matthews, JILA, University of Colorado

What was dubbed the "Bose-Einstein condensate" would also be a new phase of matter. Since only four phases exist in the entire universe -- gas, liquid, solid and plasma (it's found in electric arcs and the sun) -- discovering another phase would

certainly pump up a resume. Especially since the new matter would exist only in the lab (nature never gets that cold).

The discovery would also help prove one of the last remaining Einstein predictions, which is one reason why Carl Wieman, a professor of physics at the University of Colorado, and his colleagues began attacking the problem in the late 1980s.

"We wanted to see if real atoms could ever match the ideal system that Einstein was considering," Wieman says, "and they did match -- really quite nicely, for some experimental conditions."

He's saying that the atoms did attain a single quantum-mechanical state. And that brings us, sadly, to the

two-minute guide to quantum-mechanics

Quantum mechanics deals with the ultra-small. It describes how single atoms and atomic particles behave.

Sorry. We're not quite done.

Specifically, atoms can exist in any of millions of quantum-mechanical energy states, but not in between. Wieman compares the situation to dropping ball bearings into a series of compartments on the floor. The atoms must all fall into one compartment or another. They can't exist between compartments.

Eric Cornell, (left) and Carl Wieman with the apparatus used to achieve the Bose-Einstein condensation. Photo by Ken Abbott/University of Colorado at Boulder.

Atoms and atomic particles are like that, in terms of the energy they contain. Quantum effects allow particles to do strange things, like suddenly "tunnel" through solid objects. But these quantum-mechanical effects disappear on the macroscopic -- visible -- scale. A group of atoms exists in so many energy states that their quantum-mechanical effects are "washed out," as Wieman puts it.

The picture is different for a group of atoms in a Bose-Einstein condensate. "You have a bunch of

atoms in a single quantum state, obeying the laws of quantum mechanics as a whole," Wieman says. "Traditionally, to see a quantum state, you had to look inside a single atom. Now we can look at millions of atoms."

Bose-Einstein atoms do strange things as a group (kind of reminds The Why Files of certain teenagers...). They move like a wave when disturbed by a laser. When two condensates share one container, they sometimes repel each other. If they were gases, they would mix it up like sailors on shore leave. And sometimes they wouldn't.

Speaking of containers, what kind of thermos bottle can hold something so cold? None. Instead, the rubidium gases in the experiment are restrained in a complex magnetic "trap," a gizmo that corrals atoms, preventing their escape. Then a combination of big-league refrigeration, laser cooling, and evaporative cooling are used to chill them out.

The group led by Wieman and Eric Cornell made the first Bose-Einstein condensate in 1995, at a temperature just 200-billionths of a degree Celsius above absolute zero. Now, with experience, they've learned to make them at the "balmy" temperature of one-millionth of a degree above zero.

It turns out that the Bose-Einstein state is also evident in other curious physics, such as when some metals "superconduct" (carry electricity without resistance) at cold temperatures, or why helium, again at very cold temperatures, acts as a superfluid -- moves without resistance.

Although Einstein mentioned the Bose-Einstein state in passing, as a kind of curiosity, he thought the atoms would not interact once they'd reached it. In fact, "Most of the questions we are currently answering with the Bose-Einstein condensate are to

fill in the gaps between the 'ideal' non-interacting atom gas case Einstein considered (which is actually a bit boring), and the atoms in superfluid liquid helium," Wieman says. In that case, the atoms are packed together and hence interact very strongly, he adds.

(Although superfluid helium exists in conditions much warmer than the Bose-Einstein condensate that the Colorado researchers made, it is "widely considered a Bose-Einstein condensate," Wieman says, "even though it is in a very different sort of system than Einstein was talking about.")

And guess what? Scientists are already talking about putting the condensate to use -- less than two years after its discovery. (Sorry, no child-labor laws for physical phases.) Massachusetts Institute of Technology researchers have already made a crude atomic laser, a microscopic gun that fires small charges of "coherent" atoms -- meaning they have the same quantum-mechanical state.

The gun resembles a light laser, which shoots coherent light -- with the same quantum-mechanical state (see "First Atom Laser..." in the bibliography). Possible uses for the itsy-bitsy atomic laser include semiconductor fabrication and better atomic clocks.

Want to meet another "use" for relativity?

The Why? files back story MAP more

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